Reduced reward-driven eating accounts for the impact of a mindfulness-based diet and exercise intervention on weight loss: Data from the SHINE randomized controlled trial

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A R T I C L E   I N F O

Article history:
Received 12 November 2015
Received in revised form 5 February 2016
Accepted 6 February 2016
Available online 8 February 2016

Keywords:
Reward-driven eating
Mindful eating
Weight loss
Obesity
Behavioral intervention

A B S T R A C T

Many individuals with obesity report over eating despite intentions to maintain or lose weight. Two barriers to long-term weight loss are reward-driven eating, which is characterized by a lack of control over eating, a preoccupation with food, and a lack of satiety; and psychological stress. Mindfulness training may address these barriers by promoting awareness of hunger and satiety cues, self-regulatory control, and stress reduction. We examined these two barriers as potential mediators of weight loss in the Supporting Health by Integrating Nutrition and Exercise (SHINE) randomized controlled trial, which compared the effects of a 5.5-month diet and exercise intervention with or without mindfulness training on weight loss among adults with obesity. Intention-to-treat multiple mediation models tested whether post-intervention reward-driven eating and psychological stress mediated the impact of intervention arm on weight loss at 12- and 18-months post-baseline among 194 adults with obesity (BMI: 30–45).

Mindfulness (relative to control) participants had significant reductions in reward-driven eating at 6 months (post-intervention), which, in turn, predicted weight loss at 12 months. Post-intervention reward-driven eating mediated 47.1% of the total intervention arm effect on weight loss at 12 months \( \beta = -0.06, SE(\beta) = 0.03, p = .030, 95\% \text{ CI} (-0.12, -0.01) \). This mediated effect was reduced when predicting weight loss at 18 months \( p = .396 \), accounting for 23.0% of the total intervention effect, despite similar weight loss at 12 months. Psychological stress did not mediate the effect of intervention arm on weight loss at 12 or 18 months. In conclusion, reducing reward-driven eating, which can be achieved using a diet and exercise intervention that includes mindfulness training, may promote weight loss (clinicaltrials.gov registration: NCT00960414).

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Lifestyle interventions using diet and exercise are first-line treatments for obesity; however, these interventions tend to result in poor long-term weight loss (Barte et al., 2010; Mann et al., 2007; Wadden, Butryn, & Byrne, 2004; Wu, Gao, Chen, & Van Dam, 2009). For example, one meta-analysis of 80 studies on lifestyle interventions for weight loss reported that participants lost 5–9% of their initial body weight after 6 months, but regained half of the weight after 4 years (Franz et al., 2007). Psychological factors, including disinhibited eating (Elfhag & Rössner, 2005; McGuire,
Psychological stress may be an important target in lifestyle interventions for weight loss. In the last decade, researchers have begun to examine the effects of mindfulness-based interventions on psychological stress and obesity-related eating behaviors including emotionally or externally driven eating and binge eating (Katterman, Kleinman, Hood, Nackers, & Corsica, 2014; O’Reilly, Cook, Sprujt-Metz, & Black, 2014). Mindfulness-based interventions such as Mindfulness-based Stress Reduction (MBSR; Kabat-Zinn & Hanh, 2009) and Mindfulness-based Eating Awareness Training (MB-EAT; Kristeller & Wolfer, 2010) focus on increasing awareness of present-moment experience (e.g., internal experiences of thoughts, emotions, and body sensations), with a non-judging and accepting attitude. These interventions purport to increase self-regulatory capacity by interrupting highly conditioned patterns, decreasing emotional reactivity, and increasing distress tolerance and self-acceptance (Katterman et al., 2014; O’Reilly et al., 2014; Vago & Silbersweig, 2012).

Reductions in psychological stress and a reward-based drive to eat are both plausible mechanisms that may promote weight loss following mindfulness training. In the context of eating, mindfulness interventions aim to increase awareness of homeostatic hunger (hunger driven by caloric needs) and satiety cues (how hungry or full one feels). Mindfulness interventions also aim to cultivate abilities to distinguish between emotional and physical hunger and to tolerate food cravings or urges to eat without overeating (Alberts, Thewissen, & Raes, 2012; Forman et al., 2013; Marchiori & Papes, 2014). In the context of stress and emotion regulation, mindfulness interventions aim to bolster self-regulation, increase attentional focus, and promote adaptive coping (Kabat-Zinn & Hanh, 2009; Tang et al., 2007). Recent reviews suggest that mindfulness interventions can reduce overeating and psychological stress (Goyal et al., 2014; Katterman et al., 2014; O’Reilly et al., 2014). Yet, few long-term rigorous randomized controlled trials have examined to what extent improvements in these areas lead to better weight loss.

Daubenmier and colleagues (Daubenmier et al., In Press) conducted a randomized controlled trial comparing a 5.5-month diet and exercise intervention with versus without training in mindfulness-based eating awareness, stress management, and emotion regulation training on weight loss at 12 and 18 months post-baseline. Primary trial results indicated that mindfulness participants, relative to control participants, evidenced 1.9 kg and 1.7 kg greater weight loss at 12 and 18 months post-baseline, respectively, which approached statistical significance. Current expert opinion in mediation analysis clarifies that examination of indirect effects is not predicated on the existence of a statistically significant total (intervention) effect (Hayes, 2013). In other words, it remains important to examine factors that may account for the effect of intervention arm on weight loss, and we therefore tested for such indirect effects (Hayes, 2013; Zhao, Lynch, & Chen, 2010).

We hypothesized that mindfulness participants would experience larger reductions in reward-driven eating and psychological stress from pre-to post-intervention, and that these reductions would mediate an association between intervention arm (mindfulness versus control) and weight loss at 12 and 18 months post-baseline.

1. Method

1.1. Design

The current study reports on data from the Supporting Health by Integrating Nutrition and Exercise (SHINE) clinical trial (Clinicaltrials.gov registration: NCT00960414). Adults with obesity (BMI 30-45) were randomized in a 1:1 ratio to a 5.5-month diet and exercise weight-loss program with or without mindfulness interventions.
training for eating awareness, stress management, and emotion regulation. See (Daubenmier et al., In Press) for detailed study design and methodology, The University of California, San Francisco (UCSF) Committee on Human Research approved all study procedures and all participants provided informed consent.

1.2. Participants

Participants were recruited from the San Francisco Bay Area community through newspaper advertisements, flyers, online postings, and referrals made within UCSF medical clinics. The study was advertised as a comparison of two weight loss interventions that both involved changes in diet, exercise, and stress management, yet differed in the emphasis placed on each. To avoid selective attrition post-randomization, recruitment materials did not specifically state that mindfulness would be taught in one of the groups. Additional inclusion criteria included abdominal obesity (waist circumference > 102 cm for men and >88 cm for women) and age 18 years or older. Exclusion criteria included type 1 or type 2 diabetes mellitus (fasting glucose ≥ 126 or hemoglobin A1C (HbA1c) between 6.0 and 6.5% with an abnormal oral glucose tolerance test); pregnancy; breastfeeding or fewer than 6 months post-partum; corticosteroid and/or immune-suppressing or immune-modulating medications; prescription weight-loss medications; untreated hypothyroidism; history of or active bulimia; current meditation or yoga practice; engagement in any other structured weight management or weight-loss program; or participation in MBSR (see Daubenmier et al., In Press). If eligible, participants completed assessment procedures at two separate visits prior to randomization.

1.3. Interventions

Both intervention arms included 12 weekly group evening sessions (2–2.5 h), 3 biweekly sessions, 1 follow-up session four weeks later, and an all-day weekend session near the eighth week (5.0 h for the active control group, 6.5 h for the mindfulness intervention group) across a 5.5-month period. Registered dietitians led the control group sessions. Different registered dietitians and experienced mindfulness instructors led the mindfulness group sessions. See (Daubenmier et al., In Press) for further intervention details.

1.3.1. Diet-exercise guidelines

Diet and exercise components were the same in each intervention arm. Participants set a goal of reducing daily food intake of their choice by 500 calories. Moreover, participants were encouraged to focus on decreasing calorically dense, nutrient-poor foods such as refined carbohydrates, and increasing fresh fruits and vegetables, healthy oils, and proteins. The exercise component focused on increasing activity throughout the day as well as structured aerobic and anaerobic exercise, such as bicycling, swimming, strength training, and walking.

1.3.2. Mindfulness intervention

The mindfulness intervention included mindfulness training for eating awareness, stress management, emotion regulation, and exercise. Mindful eating practices, modeled on the Mindfulness-Based Eating Awareness Training program (MB-EAT), were designed to promote awareness and self-regulation of emotions, physical hunger, stomach fullness, taste satisfaction, food cravings, and other eating triggers in the context of reduced caloric intake (Kristeller, Wolever, & Sheets, 2014). We did not instruct participants to avoid particular foods, but encouraged them to eat favorite foods in smaller portions that fit within their calorie goals. We also encouraged participants to practice awareness and savoring of food tastes and textures, with a particular focus on drawing hedonic value from smaller amounts of highly preferred foods, such as sweets. Mindfulness training for stress management and emotion regulation incorporated components of mindfulness-based programs (Kabat-Zinn & Hanh, 2009; Segal, Williams, & Teasdale, 2012) including sitting meditation, mindful yoga, loving kindness meditations towards self and others, and mindful walking. We also taught participants a brief extended exhalation breathing technique to promote initial physiological relaxation. Home practice guidelines included meditation practice for up to 30 min a day and 6 days a week, eating meals mindfully, use of mini-meditations, and mindful walking.

1.3.3. Active control

The control intervention included additional content to ensure equivalence across intervention arms on a number of dimensions. To account for the additional time, attention, social support, and expectations of benefit that the mindfulness participants may have experienced during the mindfulness training, control participants received additional information about nutrition and physical activity. This included in-depth presentations on nutrition concepts, discussion of socio-political issues that impact food choice, how to make well-informed decisions about diet products, and tutorials on strength training with exercise bands. To account for the active ingredients of a mindfulness-based approach to stress management training, control participants received instruction in progressive muscle relaxation and cognitive-behavioral skills, although at a lower dose than in the mindfulness intervention. To reduce participant burden while ensuring perceptions of benefit, the control group sessions were reduced from 2.5 to 2.0 h after session 9. Participants completed weekly assignments at home that reinforced diet and exercise lessons.

1.4. Measures

All measures were assessed at baseline, immediately post-intervention (6 months), 12 months, and 18 months.

1.4.1. Reward-based eating

The 9-item Reward-based Eating Drive (RED) scale (Epel et al., 2014) assesses three dimensions of the hedonic drive to eat: 1) loss of control, 2) lack of satiety, and 3) preoccupation with food. It contains 2 items from the Binge Eating Scale (BES (Gormally, Black, Daston, & Rardin, 1982), 4 items from the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985), and 3 original items. Sample items include, “When I start eating, I just can’t seem to stop” (lack of control); “I don’t get full easily” (lack of satiety); and “Food is always on my mind” (preoccupation with food). In this study, participants answered items from these scales on 4-point and 3-point scales, with lower scores indicating less loss of control/lack of satiety/preoccupation with food. We therefore computed z-scores (which have a mean of 0 and standard deviation of 1) before averaging all items, as done in Study 1 of the RED validation publication (Epel et al., 2014). Higher scores reflect higher reward-driven eating. At baseline, scale internal consistency in this current sample was good (α = .80), and the mean score was 0 (SD = 0.61, range = −1.38 to 1.50).

1.4.2. Psychological stress

The 10-item Perceived Stress Scale (PSS; S Cohen, Kamarck, & Mermelstein, 1983) assesses current perceptions of stress over the past month. Participants responded to items on a scale from 0 (never) to 4 (fairly often), and the summed responses represent a total scale score. The PSS measures the degree to which one perceives aspects of one’s life as uncontrollable, unpredictable, and
overloading. Sample items include, “In the last month, how often have you felt that you were on top of things?” and “In the last month, have often have you felt nervous and “stressed?”” Higher scores reflect higher perceived psychological stress. At baseline, scale internal consistency in the current sample was good (α = .86), and the mean score was 14.41 (SD = 5.76, range = 1 to 30).

1.4.3. Weight

Participants’ weight was assessed at each study visit to the nearest 0.1 kg on a calibrated digital scale (Wheelchair Scale 6002, Scale-Tronix, Carol Stream, IL). Participants wore a hospital gown for each weighing and were weighed on the same scale at each assessment.

1.5. Analytic strategy

We tested reward-driven eating (using the RED) and psychological stress (using the PSS) at post-intervention (6 months) as mediators of the effects of the intervention arm on weight at 12 and 18 months in two separate models. Both models included baseline values of weight and the mediators (RED and PSS), as this resmi- dualized method is recommended over the use of change scores (Bland & Altman, 1994; J. Cohen, Cohen, West, & Aiken, 2003). We selected this temporal sequence to strengthen causal evidence of mediation, as recommended in the literature (Hayes, 2013). We used Mplus software to program all statistical analyses, and used Maximum Likelihood (ML) estimation and used 1000 bootstrapped samples to generate bias-corrected 95% asymmetrical confidence intervals around the indirect effect. Analyses maximally retained participants by excluding only participants who were missing both mediators (RED and PSS) assessed at 6 months and weight at 12 months (Model 1) or 18 months (Model 2). This method retains more data relative to other methods of multiple mediator analysis, such as SPSS INDIRECT (Preacher & Hayes, 2008), which includes only participants with complete data for all variables.

Unlike prior approaches toward mediation analysis (e.g., Baron & Kenny, 1986), current expert opinion in mediation methodology asserts that it is appropriate to simultaneously test all paths, including indirect effects through a mediator (Hayes, 2009; MacKinnon & Fairchild, 2009; Zhao et al., 2010), regardless of the presence of a statistically significant total intervention effect (Zhao et al., 2010). We therefore tested mediation models that simultane- ously examined RED and PSS at 6 months as mediators of the effect of intervention arm on weight at 12 months (Model 1) and 18 months (Model 2). We dummy coded intervention arm (control = 0; mindfulness = 1). Each model provided regression coefficients for the (i) effect of the intervention on the hypothesized mediators (Path A); (ii) association of the mediator variables with weight (Path B); (iii) total intervention effect (Path C, which repre- sents the effect of intervention arm on weight with no mediators in the model); (iv) direct intervention effect (Path C, which represents the effect of intervention arm on weight when mediators are included in the model); and (v) indirect intervention effect (Path AB, which represents the effect of intervention arm on weight through the mediator; see (Hayes, 2013; Pearl, 2011; Zhao et al., 2010) for detailed review of total, direct, and indirect effects). We determined the proportion of the intervention effect attributed to each medi- ator by dividing the indirect intervention effect (Path AB) by the total intervention effect (Path C).

2. Results

2.1. Participant characteristics and attrition

Participants (N = 194) in the two intervention arms were similar on baseline variables (Table 1). The majority of participants were female (82%) and White (59%). The average age was 47.0 ± 12.7 years and the average BMI was 35.5 ± 3.6. See (Daubenmier et al., In Press) for additional participant details. Retention was similar for the mindfulness and control participants at 6 months (84.0% and 77.0%; p = .21), 12 months (79.0% and 74.0%, p = .50), and 18 months (81.0% and 71.0%, p = .13). See Table 2 for mean values of study variables at each assessment.

Two participants were missing both mediators at 6 months and weight at 12 (but not 18) months due to inability to attend those assessments. They were therefore excluded from the 12-month analysis and retained in the 18-month analysis. One participant was missing both mediators at 6 months and weight at 18 (but not 12) months due to inability to attend those assessments. This participant was therefore excluded from the 18-month analysis yet retained in the 12-month analysis. Sample sizes in the 12-month (n = 158) and 18-month (n = 159) analyses were similar.

2.1.1. Weight loss at 12 months (model 1)

As shown in Fig. 1, the effect of the intervention arm on RED at 6 months was statistically significant (β = −.36; p = .003) whereas the effect on PSS approached significance (β = −.21; p = .096). This means that mindfulness relative to control participants re- ported lower levels of RED and marginally lower levels of PSS. As shown in Table 3 and consistent with results from the randomized trial (Daubenmier et al., In Press), the effect of intervention arm on initial weight loss at 12 months approached significance (total ef- fect; p = .077). Inclusion of RED and PSS in the model, however, reduced this effect (direct effect; p = .308). RED at 6 months was positively associated with weight loss at 12 months (β = .018; p = .001), but RED was not (β = −.03; p = .539).

The largest indirect effect through RED explained 47.1% of the total intervention effect on weight loss at 12 months (see Table 3). In contrast, the indirect effect through PSS explained 4.5% of the total intervention effect on weight loss at 12 months, and was not statistically significant. Thus, we observed an indirect effect (in the absence of total or direct effects) of intervention arm on weight loss at 12 months through RED.

2.1.2. Weight loss at 18 months (model 2)

As shown in Fig. 1, and similar to Model 1, the effect of inter- vention arm on RED at 6 months was statistically significant (β = −.35; p = .004) whereas the effect on PSS approached sig- nificance (β = −.21; p = .094). As shown in Table 3, the effect of intervention arm on weight loss at 18 months was not statistically significant before (total effect; p = .296) or after (direct effect; p = .472) accounting for RED and PSS. Neither RED (β = .06; p = .350) nor PSS (β = 0.03; p = .556) were significantly associated with weight loss at 18 months. As shown in Table 3, the indirect effects via PSS (which explained 7.0% of the total effect) and RED (which explained 23.0% of the total effect) were not statistically significant.

3. Discussion

We examined reward-driven eating and psychological stress as two mechanisms by which a 5.5-month diet and exercise inter- vention with or without adjuvant mindfulness training might impact long-term weight loss in adults with obesity. Mindfulness participants reported significantly lower levels of reward-driven eating than control participants at post-intervention (6 months). Furthermore, reductions in reward-driven eating at 6 months mediated the effect of intervention arm on weight loss at 12 months. Hence, these data illustrate that among adults with obesity, mindfulness training, when combined with diet and
Table 1
Baseline participant characteristics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD) or N (%)</th>
<th>Full sample (N = 194)</th>
<th>Mindfulness (n = 100)</th>
<th>Control (n = 94)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>47.0 (12.7)</td>
<td>47.2 (13.0)</td>
<td>46.8 (12.4)</td>
<td></td>
</tr>
<tr>
<td>Sex (female)</td>
<td>160 (82.0%)</td>
<td>79 (79.0%)</td>
<td>81 (86.0%)</td>
<td></td>
</tr>
<tr>
<td><strong>Race/Ethnicity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>10 (5.2%)</td>
<td>7 (7.0%)</td>
<td>3 (3.2%)</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>115 (59.3%)</td>
<td>65 (55.0%)</td>
<td>50 (53.2%)</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>25 (12.9%)</td>
<td>13 (13%)</td>
<td>12 (12.8%)</td>
<td></td>
</tr>
<tr>
<td>Latino</td>
<td>23 (11.9%)</td>
<td>7 (7.0%)</td>
<td>16 (17.0%)</td>
<td></td>
</tr>
<tr>
<td>Asian/Paciﬁc Islander</td>
<td>19 (9.8%)</td>
<td>8 (8%)</td>
<td>11 (11.7%)</td>
<td></td>
</tr>
<tr>
<td>Native American</td>
<td>2 (1.0%)</td>
<td>0 (0.0%)</td>
<td>2 (2.1%)</td>
<td></td>
</tr>
<tr>
<td><strong>Health Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>97.2 (14.4)</td>
<td>97.7 (14.1)</td>
<td>96.7 (14.8)</td>
<td></td>
</tr>
<tr>
<td>Body Mass Index (BMI)</td>
<td>35.5 (3.6)</td>
<td>35.4 (3.5)</td>
<td>35.6 (3.8)</td>
<td></td>
</tr>
<tr>
<td>Reward-based Eating Drive</td>
<td>0.00 (0.61)</td>
<td>−0.02 (0.59)</td>
<td>0.02 (0.63)</td>
<td></td>
</tr>
<tr>
<td>Perceived Stress Scale</td>
<td>14.41 (5.76)</td>
<td>14.38 (6.06)</td>
<td>14.43 (5.46)</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Reward-based Eating Drive (RED) scale scores are computed as the mean of all items following item-level z-score transformation.

Table 2
Means and standard deviations for study variables for each model.

<table>
<thead>
<tr>
<th>Model</th>
<th>Variable</th>
<th>Baseline (M, SD)</th>
<th>6 Months (M, SD)</th>
<th>12 Months (M, SD)</th>
<th>18 Months (M, SD)</th>
<th>Baseline (M, SD)</th>
<th>6 Months (M, SD)</th>
<th>12 Months (M, SD)</th>
<th>18 Months (M, SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1: 12 months (n = 158)</td>
<td>RED</td>
<td>0.04 (0.61)</td>
<td>−0.07 (0.60)</td>
<td>−0.09 (0.57)</td>
<td>−0.06 (0.62)</td>
<td>0.05 (0.59)</td>
<td>0.12 (0.61)</td>
<td>0.10 (0.66)</td>
<td>0.07 (0.69)</td>
</tr>
<tr>
<td></td>
<td>PSS</td>
<td>14.27 (6.04)</td>
<td>13.18 (6.01)</td>
<td>14.13 (6.33)</td>
<td>13.31 (5.89)</td>
<td>14.41 (5.35)</td>
<td>14.22 (5.53)</td>
<td>14.54 (6.86)</td>
<td>14.54 (5.91)</td>
</tr>
<tr>
<td></td>
<td>Weight</td>
<td>98.10 (13.98)</td>
<td>92.5 (13.67)</td>
<td>92.64 (13.47)</td>
<td>92.9 (14.63)</td>
<td>95.09 (13.25)</td>
<td>90.33 (12.05)</td>
<td>90.93 (14.29)</td>
<td>90.74 (14.08)</td>
</tr>
<tr>
<td>Model 2: 18 months (n = 159)</td>
<td>RED</td>
<td>0.03 (0.62)</td>
<td>−0.07 (0.60)</td>
<td>−0.09 (0.57)</td>
<td>−0.06 (0.62)</td>
<td>0.04 (0.60)</td>
<td>0.12 (0.60)</td>
<td>0.10 (0.65)</td>
<td>0.08 (0.680)</td>
</tr>
<tr>
<td></td>
<td>PSS</td>
<td>14.12 (6.18)</td>
<td>13.18 (6.01)</td>
<td>14.13 (6.33)</td>
<td>13.31 (5.89)</td>
<td>14.30 (5.40)</td>
<td>14.08 (5.58)</td>
<td>14.53 (6.60)</td>
<td>14.44 (5.90)</td>
</tr>
<tr>
<td></td>
<td>Weight</td>
<td>98.35 (14.08)</td>
<td>92.5 (13.67)</td>
<td>92.64 (13.47)</td>
<td>92.9 (14.63)</td>
<td>94.86 (13.30)</td>
<td>90.27 (11.96)</td>
<td>90.87 (14.18)</td>
<td>90.66 (13.96)</td>
</tr>
</tbody>
</table>

*Note.* RED = Reward-based Eating Drive Scale; PSS = Perceived Stress Scale; Weight in Kg. RED Scale scores are computed as the mean of all items following item-level z-score transformation.

Fig. 1. Reward-driven eating and psychological stress as mediators of the effects of intervention arm (control versus mindfulness) on weight at 12- and 18-months post-baseline.
exercise, may promote greater reductions in reward-driven eating compared to diet-exercise programs without mindfulness training. In addition, these reductions were, in turn, associated with weight loss at 12 months, suggesting that decreases in reward-driven eating were responsible for a significant proportion of the weight loss experienced by participants, and this effect held after accounting for any mediating effects of changes in perceived stress. These results indicate that decreases in reward-driven eating are associated with longitudinal decreases in weight, thus building on prior research documenting cross-sectional and longitudinal associations between reward-driven eating and BMI (Epel et al., 2014).

Thus, reward-driven eating may be an important target of intervention for lifestyle programs focused on weight loss. Many individuals with obesity struggle to lose weight, maintain weight loss, or cope with implementation of lifestyle changes that can accompany exercising and their distribution (Tsenkova, Boylan, & Ryff, 2013). Future studies may also select for individuals who report more stress-related eating, given recent data linking stress-related eating to greater central fat distribution (Epel, Forthcoming; Sinha & Jastreboff, 2013).

Mindfulness participants evidenced a trend toward reduced general perceptions of stress at post-intervention. Future studies may more clearly delineate associations between stress reduction and obesity by selecting individuals who report high levels of work-related or family stress and using measures that specifically assess these stressors (Gryzwacz, Almeida, & McDonald, 2002; Schuster, Kessler, & Jr, 1990; Vagg & Spielberger, 1998). Additionally, future studies should capture both experiences of psychological stress and maladaptive responses to psychological stress (Laitinen, Ek, & Sovio, 2002). Future studies may also tailor intervention content to directly address stressors specific to their study populations (e.g., work- or family-related stress, stress-induced or emotional eating). Finally, we compared the mindfulness intervention against a rigorous active control that included limited progressive muscle relaxation training and cognitive behavioral methods to manage stress eating. It may be that these added components reduced the effect size of the between-arm difference in changes in perceived stress. This study potentially demonstrates the importance of comparing mindfulness interventions against active control conditions, as other rigorous tests of mindfulness-based interventions using active controls have found null results (Goldberg et al., 2015; MacCooon, MacLean, Davidson, Sarcon, & Lutz, 2014; Shallcross et al., 2015).

The drive to overeat highly palatable food for reward may represent one important behavioral obstacle to weight loss. Craving is a key driver of compulsive and reward-driven behavior (Pelchat, 2002; Volkow et al., 2012), and mindfulness-based approaches have shown promise in targeting reductions in craving (Albers, Mulkens, Smeets, & Thewissen, 2010; Alberts et al., 2012; Forman & Butryn, 2015). The mindful eating techniques taught in this intervention involved identifying and responding adaptively to food cravings, as well as providing skills for emotion regulation that would allow individuals to sit with, rather than act upon, the physical and psychological discomfort that can accompany the experience of food craving (Hamilton, Fawson, May, Andrade, & Kavanagh, 2013; May, Andrade, Kavanagh, & Hetherington, 2012).

Altering the hypothesized associations between stress and obesity. For example, longitudinal studies suggest that stress due to work-related issues and family relationships predict weight gain among obese and overweight individuals (Kivimäki et al., 2006; Nyberg et al., 2012). Mindfulness participants evidenced a trend toward reduced general perceptions of stress at post-intervention. Future studies may more clearly delineate associations between stress reduction and obesity by selecting individuals who report high levels of work-related or family stress and using measures that specifically assess these stressors (Gryzwacz, Almeida, & McDonald, 2002; Schuster, Kessler, & Jr, 1990; Vagg & Spielberger, 1998). Additionally, future studies should capture both experiences of psychological stress and maladaptive responses to psychological stress (Laitinen, Ek, & Sovio, 2002).

One possible explanation for these findings is that our study sample reported below-national levels of psychological stress (Sheldon Cohen & Janicki-Deverts, 2012). Thus, this sample may have not been poised to experience large reductions in stress or stress-related eating. A second possible explanation is that the brief 10-item Perceived Stress Scale (PSS) is a retrospective index of general psychological stress. It therefore does not assess nuanced information on types of stress, which is an important determinant of associations between stress and obesity (Block et al., 2009).
not predict weight loss at 18 months (Fig. 1). The effects of intervention arm (mindfulness versus control) on weight loss were roughly similar at 12 months (M diff across arms = 1.9 kg) and 18 months (M diff across arms = 1.7 kg), with the mindfulness participants losing more weight (Daubenmier et al., In Press). Hence, the weakening of the mediation effect in the 18-month analysis was not the result of a sizable loss of intervention effects on weight. On note, reward-driven eating also did not show meaningful changes between 12 and 18 months (Table 2). This underscores conclusions of other trials reporting the differential importance of distinct mechanisms impacting weight change during, shortly after, and longer after, weight-loss interventions (Kiernan et al., 2013).

A diversity of biological, environmental, and psychological factors impact weight gain and obesity status, including genetics, family history, the food environment, psychological stress, and the neurocircuity of reward. Obesity reflects a variety of different causes or primary dysregulations. Identifying the most potent targets and developing interventions that specifically address them will be pivotal to increasing the effectiveness of obesity interventions (Kiernan, 2012). Data presented here add to literature suggesting that reward-driven eating tracks with weight change gets and developing interventions that specify or by individuals the facets of stress which may not have assessed the facets of stress that contribute to excess adiposity. Specific measures of type of stress (Cryzwasz et al., 2002; Schuster et al., 1990; Vagg & Spielberger, 1998) and stress-induced eating (Burgess, Turan, Lokken, Morse, & Boggiano, 2014; Tsenkova et al., 2013) may help clarify associations among mindfulness training, psychological stress, eating behavior, and weight loss. Third, there was not a statistically significant total effect of intervention arm on weight loss, which suggests that the associations between intervention components and their hypothesized intervention targets might be strengthened through further intervention component refinement.

4. Conclusion

These analyses suggest that integrating mindfulness components into a diet-exercise weight loss intervention leads to greater reductions in reward-driven eating. These reductions in reward-driven eating, in turn, are associated with greater weight loss, suggesting that decreases in reward-driven eating are a mechanism by which interventions impact weight change. Future interventions should target reductions in reward-driven eating so as to improve weight loss outcomes.

Acknowledgment

This research was supported by funding from the National Institutes of Health (NCI) to Frederick M. Hecht (1P01AT005013; K24AT007827) and Jennifer Daubenmier (K01AT004199). Ashley E. Mason was supported by The National Institutes of Health (NCI) [T32AT003997]. This research was also supported by funding from the National Institutes of Health (NHLBI) to Elissa S. Epel (U01HL097973). This publication was supported by the National Center for Advancing Translational Sciences, National Institutes of Health, through UCSF-CTSI Grant Number UL1 TR000004. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the NIH.

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